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Drivers and barriers to the adoption of precision irrigation technologies in olive and cotton farming—Lessons from Messenia and Thessaly regions in Greece

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ABSTRACT

Precision irrigation technologies have the ability to increase crop yields and productivity, optimize water use efficiency and minimise environmental impact. Despite this, adoption of precision irrigation technologies by farmers remains low and slow. This research investigated the behavioural factors that affect farmers' intention to adopt precision irrigation technologies in olive groves and cotton production in the regions of Messenia and Thessaly of Greece respectively. Data were collected through in-depth face-to-face interviews using an extensive questionnaire, involving a sample of 82 farmer respondents. The findings reveal that environmental consciousness has the most substantial impact on farmers' intention to adopt precision irrigation technologies. It is followed by perceived economic benefits, perceived behavioural control, and perceived compatibility, all of which contribute significantly to the intention to adopt. Furthermore, risk aversion, although displaying a smaller effect, remains a notable consideration in the analysis. These results offer valuable insights into technology adoption in agriculture and bear implications for future strategies and policy recommendations.

1. Introduction

The global agricultural sector is a major user of freshwater, accounting for around 70 % of the world's consumptive use of freshwater resources. However, traditional agricultural irrigation methods face substantial challenges, including inefficiencies in water usage and suboptimal agricultural productivity. Additionally, the unpredictable impacts of climate change and global warming have disrupted rainfall patterns, affecting crop water needs, which vary based on seasonal and environmental factors such as weather conditions [1]. According to the findings of the Intergovernmental Panel on Climate Change (IPCC), countries within the Mediterranean Basin are poised to experience more pronounced effects of climate change. These effects will manifest primarily as increasing temperatures, a reduction in the overall water balance, and an increase in the frequency of extreme weather events [2]. Specifically, in the Mediterranean Basin, there are two major challenges: less rainfall and rising temperatures, especially during the summer period. These lead to water shortages in many areas, affecting rivers, lakes, and water reservoirs. Water shortages are a significant threat to food and energy security, especially for agriculture, resulting in lower crop yields and jeopardising sustainable development. Adding to these concerns, the world's population is expected to reach 9.1 billion by 2050, increasing the demand for food and energy, and making the issues of water scarcity and rising temperatures in the Mediterranean Basin even more pressing [3].

Greece, a Mediterranean Basin country experiencing the impacts of climate change [4], is one of the largest producers olive and cotton in Europe. In the olive cultivation sector, Greece consistently maintains its position among the top three European countries, alongside Spain and Italy, accounting for approximately 15 % of the total 4.6 million hectares of olive groves within the European Union in 2017 [5,6]. Moreover, cotton is primarily grown in the European Union on around 320,000 ha, with Greece dominating the cotton area at 80 %, followed by Spain and Bulgaria [7,8]. Although cotton and olive trees possess impressive adaptability to diverse environmental conditions, they remain vulnerable to the impacts of climate change, particularly concerning their growth and need for irrigation [9,10].

Olive trees thrive in regions with as little as 400 mm of annual precipitation—below the traditionally recommended 600 mm threshold [11]. Despite the inherent drought tolerance of olive trees, modern agriculture increasingly employs irrigation for olive cultivation to optimize yields and address the challenges posed by shifting climate

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patterns and the rising demand for olive-related products. As a result, implementing efficient irrigation management strategies and adopting precision irrigation technologies play a crucial role in ensuring sustainable and resource-efficient olive farming [9].

Cotton cultivation requires 600–1000 mm of precipitation during its entire growth phase, further highlighting the importance of water in its cultivation. The absence of sufficient water for cooling poses a significant threat to cotton plants due to excessive heat. Consequently, cotton's growth and temperature management heavily rely on irrigation, whether from precipitation or irrigation. Precise timing and proper water application during the growing season become critical, as any disruptions in water availability can hinder plant development, potentially resulting in reduced yields. Notably, cotton farming significantly relies on irrigation, accounting for approximately 53 % of the world's total irrigation, with irrigated fields producing 3000–4000 kg of seed cotton per hectare, compared to 1000–2000 kg in non-irrigated fields. Consequently, over 73 % of the world's cotton fibre originates from irrigated cultivation [10,12].

To address water scarcity and subsequent sustainability challenges, precision irrigation systems have emerged as a practical solution [13]. Precision irrigation, in the context of precision agriculture, is a technologically driven practice that involves the accurate and timely assessment of crops' water requirements, followed by the precise delivery of the exact amount of water they need. This method incorporates information systems, communication networks, and real-time control mechanisms to monitor and respond to crops' dynamic water needs, taking into account factors such as soil variations, plant responses, and changing weather conditions. The overarching goal of precision irrigation is twofold: firstly, to optimize water usage and enhance the efficiency of crop cultivation, and secondly, to alleviate the pressure on natural water resources [14,15]. Leveraging technologies like Global Positioning System (GPS) and Geographic Information Systems (GIS), in conjunction with computer modelling, remote sensing, and advanced information processing, enables the collection of comprehensive field data pertaining to spatial and temporal variations in crop production [16,17].

Previous research has consistently shown that the adoption of precision irrigation technologies leads to elevated crop yields and enhances the efficiency of water, soil, nutrients, and other agricultural inputs [14]. For instance, a study implementing Variable Deficit Irrigation (VDI) in cotton production, integrating remote sensing, soil analyses, and crop growth modelling for irrigation management, reported a substantial increase of approximately 28.7 % in yield, accompanied by a 24.9 % reduction in water usage. This approach also demonstrated enhanced nitrogen and fertilizer productivity [18]. Similar positive outcomes have been observed in other studies related to cotton cultivation that utilized irrigation Decision Support Systems (DSS) [1,19–21] and Variable Rate Irrigation (VRI) [22–27]. These positive results extend to olive cultivation, where a study utilizing DSS-based irrigation management demonstrated its effectiveness as a sustainable and resource-efficient choice, resulting in a notable 42.1 % reduction in water and energy compared to conventional practices [28]. In another study focused on Scientific Irrigation Scheduling (SIS) in olive groves, soil moisture sensors coupled with a drip irrigation system resulted in water savings between 17 % and 25 %, along with yield enhancements of 8 % and 9 % [29]. Furthermore, studies have proven that employing remote monitoring and control systems [30,31], as well as a combination of remote and proximal sensing technologies, can improve water efficiency in olive cultivation [32]., Despite the evidence of the advantages of precision irrigation technologies, the adoption and widespread implementation of these technologies have been relatively slow, especially due to high initial investment costs and the lack of farmer skills required in the integration of the new technologies into current farming operations. Recent reviews of adoption studies in precision agriculture highlighted the lack of substantial research on the behavioural factors affecting farmer adoption of precision agriculture technologies [33,34]. Notably, the vast majority of studies has focused on farm and agro-ecological related factors, socio-demographics, and technology-related characteristics [35]. Therefore, there is a pressing need to understand the factors influencing its adoption, a key step toward more effective implementation [36]. A plethora of theories and models have emerged to shed light on the factors that affect behaviour and adoption of technologies, with the most prominent being the Rogers' Theory of Diffusion of Innovation, Davis et al.'s Technology Acceptance model and Ajzen's Theory of Planned Behaviour. Rogers' Theory of Diffusion of Innovation (1983) serves as a foundational framework, providing a systematic roadmap for adoption. Within this theoretical framework, Rogers identified five essential attributes that profoundly influence the adoption rates of innovations: relative advantage, measuring an innovation's superiority; compatibility, assessing alignment with pre-existing values and needs; complexity, assessing the perceived ease of use; trialability, indicating the potential for experimentation and testing; and observability, highlighting the visibility of tangible benefits associated with the innovation. Innovations scoring higher on these attributes tend to be adopted more swiftly [37,38].

Simultaneously, the Technology Acceptance Model (TAM), introduced by Davis et al. (1989), directs our attention to two key factors: perceived usefulness, which reflects the degree to which individuals believe that a particular system will enhance their job performance, and perceived ease of use, related to the perception of how effortless it will be to utilize the system. Both these beliefs are significantly influenced by the design characteristics of the technology. TAM has undergone continuous evolution, with researchers introducing new variables and complicated relationships into the model. As a result, it has become a widely cited framework for comprehending technology acceptance [39,40].

Ajzen's Theory of Planned Behaviour (TPB) (1991) serves as a central framework, explaining how individuals arrive at decisions regarding the adoption of technologies such as Precision Agriculture. It places significant emphasis on the role of attitudes and intentions in shaping final decisions. Intentions and actual behaviour are determined by two additional factors, namely, subjective norms (a person's perceptions about the community's attitude to certain behaviour) and perceived behavioural control (a person's perception of ease or difficulty in carrying out a behaviour). These theories provide a promising theoretical framework to examine the behavioural factors that influence adoption of precision irrigation technologies [34,41].

Extant research with respect to the behavioural factors that foster or hinder adoption of precision irrigation technologies is scarce. Some studies have concentrated on investigating a range of factors that influence the adoption of smart farming technologies [42–44]. Partalidou et al. [43] identified the primary barriers to adoption as a lack of knowledge, lack of guidance or support systems for the effective utilization of technology, and high initial investment costs. Kernecker et al. [42] focused on various technology-related factors and highlighted the importance of perceived usefulness, compatibility, ease of use, and perceived benefits in driving adoption of precision agriculture technologies. Systemic factors also play a role with financial support, legal framework, extension and advisory services, and the availability of informational sources playing a crucial role in bridging the gap between technology providers and end-users [42,44]. However, there is a lack of empirical studies specifically investigating the context of precision irrigation technologies and the associated determinants of farmers' adoption. This paper seeks to address this gap in the literature and aims to analyse the determinants of farmers' adoption precision irrigation in olive and cotton farming in Greece by focusing on certain individual behavioural factors.

2. Theoretical model

In this section, we present our theoretical framework for understanding the adoption of precision irrigation (Fig. 1). In this framework,

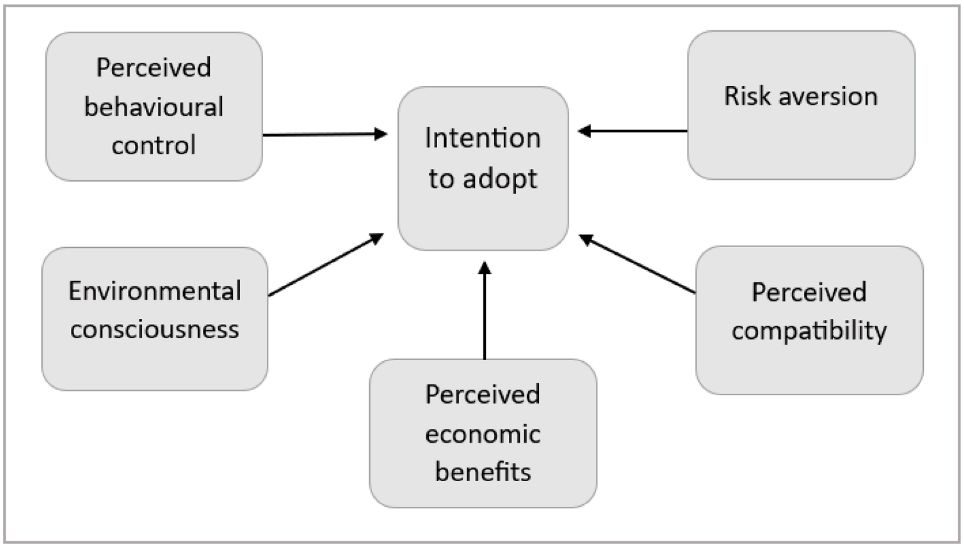

Fig. 1. Hypothesized adoption intention model for precision irrigation.

we propose a series of hypothesis, labelled as H1, H2, and so forth, which guide our research. Each hypothesis addresses a particular research question, and we will explain each one further in the upcoming sections.

2.1. *Perceived behavioural control*

In the context of socio-psychological factors, individuals' intentions play a crucial role in predicting their actual engagement in specific behaviours. This principle holds true for farmers as well, where the belief that they possess the necessary skills and time required for technology adoption significantly influences their likelihood of adopting it [45]. Perceived behavioural control is a key factor of Ajzen's Theory of Planned Behaviour and refers to an individual's belief in their ability to perform a specific behaviour. This belief is shaped by their perception of various control factors that can either make the behaviour easier or more difficult to execute. These control factors encompass a range of aspects, such as one's skills and abilities, the availability of time, money, and other resources, as well as the cooperation and support of others [46]. In the context of adopting new technologies, perceived behavioural control relates to farmers' perceptions of the ease or difficulty associated with the adoption process. Previous studies found that farmers exhibited a higher willingness to embrace new agricultural techniques when they perceived that the learning requirements were manageable and substantial investments were not necessary [47–50].

H_1: Perceived behavioural control has positive correlation with adoption of precision irrigation technologies.

2.2. *Environmental consciousness*

Another individual factor that may affect farmer adoption is environmental consciousness. The importance of examining environmental consciousness lies in its ability to predict subsequent environmental actions. Environmental attitudes, which are viewed as enduring beliefs shaping how individuals interact with the environment, are expected to guide individuals towards corresponding pro-environmental behaviours. Based on Schwartz's theory, individuals are more likely to take action when they are aware of the positive consequences of their actions and feel a sense of responsibility for helping the environment [51]. Prior research has delved into the influence of environmental consciousness on the adoption of environmentally friendly agricultural practices, with findings indicating that cultivating a strong personal sense of responsibility for environmental issues, such as water pollution [52] along with maintaining a heightened awareness of environmental issues [53], acts as a substantial catalyst for embracing environmentally friendly agricultural practices.

H_2: Environmental consciousness has positive correlation with adoption of precision irrigation technologies.

2.3. *Perceived economic benefits*

Perceived economic benefits is expected to be a key influencing factor in the adoption of precision irrigation. Perceived economic benefits refer to the expected economic rewards that farmers anticipate reaping after investing in precision irrigation practices. These rewards may manifest as heightened productivity, increased profitability, and savings in labour. When farmers believe that adopting sustainable practices will bring them economic advantages, they are more inclined to embrace such practices [54]. Understanding the potential advantages of increased yields and cost savings increases confidence, thereby alleviating their uncertainties and fears associated with adopting agricultural technologies [55].

H_3: Perceived economic benefits have positive correlation with adoption of precision irrigation technologies.

2.4. *Perceived compatibility*

Perceived compatibility is a critical factor to investigate when examining the adoption of technology. This concept is closely tied to the widely recognized Technology Acceptance Model (TAM). Perceived compatibility, within the context of technology adoption, delves into the degree to which individuals perceive a new technology as aligning with their established values, past experiences, work routines, and personal preferences [56]. The influence of perceived compatibility on users is substantial. It significantly shapes their attitudes and intentions regarding the acceptance and utilization of technology. For example, a producer who is committed to traditional agricultural practices is unlikely to incorporate new technologies into their system because it is incompatible with the existing values and norms of its farming practices [34].

H_4: Perceived compatibility has positive correlation with adoption of precision irrigation technologies.

2.5. Risk aversion

Risk aversion has a substantial influence on the adoption of precision agricultural technologies, primarily due to the significant initial investment costs that heighten financial risk [57]. Risk aversion refers to the tendency to avoid risks and have low risk tolerance. Farmers are constantly faced with various risks which can be associated with productions risks (e.g., yield variability due to climate change or yield loss), policy risks (changes in legal framework, subsidies, etc.), market risks (e.g., changes in the prices of agricultural inputs, market demand) [58]. Studies have found that farmers who are unwilling to take risks tend to overestimate the costs associated with adopting a new technology and show lower intention to invest in sustainable agricultural practices [52,53].

H_5: Risk aversion has negative correlation with adoption of precision irrigation technologies.

3. Materials and methods

3.1. Study area

The research took place in two regions of Greece: Messenia with olive producers and Thessaly with cotton producers. Messenia is situated in the southwestern area of the Peloponnese Peninsula, with its regional capital being Kalamata. Messenia's economic backbone centres on agriculture, particularly the cultivation of olive trees for olive oil and edible olives, establishing it as a major player in Europe's olive oil industry. The predominant olive variety cultivated in this region is Kalamon. In 2016, agricultural land in the Messenia region comprised a significant 25 % (734.3 km^2) of the total land area, with olive groves dominating, covering the 82 % (604.1 km^2) of this agricultural expanse. Messenia experiences a temperate climate characterized by mild winters and hot summers. The mean annual temperature typically ranges from 13°C to 19°C. During winter, the lowlands and coastal regions maintain an average temperature between 17°C and 21°C, thanks to warm and humid south winds. In Messenia, the annual precipitation averages between 800 and 1600 mm, varying with the region's elevation. Winter in the area is marked by the passage of depressions forming over the Mediterranean Sea, while in summer, the region is influenced by heat waves from North Africa [59,60].

The second region, Thessaly, is located in central Greece. Thessaly is a major cotton-growing area cultivating approximately 100,000 ha of cotton on average, out of the 240,000 ha of the national cotton cultivation which constitutes 80 % of the total European production [61,62]. The climate in the western and central regions of Thessaly is characterized by continental conditions, resulting in cold winters and hot summers with significant temperature fluctuations. Conversely, the coastal areas of Thessaly enjoy a more Mediterranean climate. During the summer months, Thessaly experiences hot and dry conditions, with July and August temperatures soaring to 40°C. On average, Thessaly receives approximately 700 mm of annual precipitation, but this varies significantly across the region. In the central plain, rainfall averages around 400 mm, while the western mountain peaks can receive over 1850 mm of rainfall. During the summer there is minimal rainfall [63].

3.2. Survey design

A survey was developed with the aim of examining the factors influencing the adoption of precision irrigation by olive growers in Messenia and cotton growers in Thessaly. The questionnaire initially asked participants about their knowledge with respect to precision irrigation technologies and subsequently provided a definition before eliciting participants' responses about whether they have previously adopted such a technology. The questionnaire consisted of the following main sections: 1) farmer demographics, 2) farm characteristics, 3) behavioural factors affecting adoption and 4) intention to adopt precision irrigation technologies. Independent variables included perceived behavioural control, environmental consciousness, perceived economic benefits, perceived compatibility, risk aversion while the dependent variable was the intention to adopt precision irrigation technologies. For each variable, respondents were required to indicate their level of agreement or disagreement with the corresponding statement using a 5-point Likert scale, where 1 signified "strongly disagree" and 5 represented "strongly agree". Scales were adopted from previous literature and adapted to the context of precision irrigation, where needed. Variables were measured using at least three item statements to ensure consistency and reliability of measurement. Positive- and negative-phrased statements were used, and negative statements were then recoded for statistical analysis. Finally, prior to the distribution of the questionnaire, it was piloted with 20 farmers from both Messenia and Thessaly and the wording was adjusted based on their feedback. Table 1 provides a list of items used to measure the study variables, along with their corresponding references and the Cronbach's alpha values, which gauge the internal consistency of these items. As is evident from Table 1 in all cases Cronbach's alpha exceeded 0.7, a minimum threshold indicating acceptable reliability.

3.3. Data collection

Data collection lasted for three months in the period between July and September 2022. The questionnaire was administered face-to-face. The direct face-to-face interactions with the targeted producers allowed the research team to address any queries, provide additional context, and ensure a comprehensive understanding of the questionnaire. In collaboration with major farmer associations in Messenia and Thessaly, the snowballing technique was employed to facilitate farmer recruitment and data collection. A total number of 82 farmers was achieved, with 42 from Thessaly and 40 from Messenia, which has been regarded as representative due to the length of the questionnaire and its non-technical dimension of precision irrigation.

3.4. Data analysis

The data collected were manually inputted into the Excel for further processing and analysis. The dataset was further imported to IBM SPSS Statistics 21 for the analysis. Initially, data were checked for missing values by examining frequencies to ensure there were no missing data. Subsequently, descriptive analysis was conducted to gain an understanding of the data properties, including standard deviation and mean for continuous variables, as well as frequency analysis for categorical variables. For variables measured on a Likert scale that consisted of three or more questions, a reliability analysis was performed using Cronbach's alpha. As previously indicated, Cronbach's alpha demonstrated reliability levels exceeding the acceptable threshold. Consequently, the questions were combined into a single variable which was calculated as the average of responses to each item statement. Afterwards, a correlation analysis was performed, specifically using Pearson's correlation coefficient, to assess the degree and direction of relationships between various variables in our study. Subsequently, a multiple linear regression analysis was conducted in SPSS to examine the impact of independent variables on the dependent variable. Finally, the sample was divided into two groups: cotton farmers in Thessaly and olive farmers in Messenia. To assess differences between the two groups, independent samples *t*-tests were used for continuous variables, while Chi-square statistics were employed for comparisons of categorical variables.

Table 1
Study variables, measurement items, references, and Cronbach's alpha coefficients.

Variables	Items	No.	Sources	Cronbach's alpha
Perceived behavioural control	It is easy for me to find the information I need for the use of precision irrigation technologies in my cultivation.	1	[64]	.77
	I have the technical skills to implement precision irrigation in my cultivation.	2	[64]	
	I can afford the financial expenses for the implementation of precision irrigation in my cultivation.	3	[64]	
	I have the time to dedicate to the use of precision irrigation technologies in my cultivation.	4	[64]	
	Precision irrigation cannot be easily applied in my cultivation.	5	[64]	
Environmental consciousness	It is my personal responsibility to help protect the environment.	1	[65]	.71
	It is important to me to protect the environment even if it slows down economic growth of my farming activities.	2	[65]	
	My actions have an impact on the environment.	3	[65]	
	The well-being of the community depends on the preservation of the environment.	4	[65]	
Perceived economic benefits	Adoption of precision irrigation will lead to improved technical performance.	1	[54]	.84
	Adoption of precision irrigation will lead to improved economic performance.	2	[54]	
	Adoption of precision irrigation will lead to labour savings.	3	[54]	
	Adoption of precision irrigation will lead to lower costs.	4	[54]	
	Adoption of precision irrigation will lead to higher product selling price.	5	[54]	
	Adoption of precision irrigation will lead to higher productivity.	6	[54]	
	Adoption of precision irrigation will lead to lower economic risk.	7	[54]	
	Adoption of precision irrigation will lead to more profits.	8	[54]	
Perceived compatibility	The use of precision irrigation is consistent with my beliefs.	1	[66]	.85
	Precision irrigation aligns with my work values.	2	[66]	
	The use of precision irrigation is compatible with my working style.	3	[66]	
Risk aversion	I exhibit general risk aversion.	1	[67]	.83
	I exhibit risk aversion concerning my personal health.	2	[67]	
	I exhibit risk aversion in the context of financial matters.	3	[67]	
Intention to adopt	I plan to use precision irrigation technologies this year.	1	[68]	.84
	I intend to use precision irrigation technologies for the next 5 years.	2	[68]	
	I will use precision irrigation technologies regularly in the future.	3	[68]	

4. Results

4.1. Sociodemographic characteristics of producers and farm characteristics

The total number of responses was 82. From the 82 surveyed farmers, 44 % indicated that they were familiar with precision irrigation technologies, whereas the remaining 56 % reported not having knowledge of these technologies (Fig. 2). Furthermore, only 20 % of the respondents had previously employed precision irrigation technologies, while 80 % respondents had not yet incorporated them into their agricultural practices (Fig. 3).

Comparisons between cotton and olive farmers in Thessaly and Messenia revealed that no significant differences were observed in their knowledge of precision irrigation technologies ($\chi2(1) = 0.410$, $p = 0.522 > 0.05$) and their previous use of such technologies ($\chi2(1) = 1.012$, $p = 0.314 > 0.05$).

Table 2 displays the sociodemographic characteristics of respondents. Most respondents in the study are males (90.2 %) aged between 36 and 45 years old (24.4 %). A majority of them have completed high school education (42.7 %), while a significant number hold undergraduate degrees (40.2 %). More than half of farmers report annual incomes of 20,000 euros or lower (51.2 %). Income is primarily derived from agricultural activities, constituting more than 75 % of their income sources (30.5 %). Additionally, farmers in the survey report having 1 to 10 years of farming experience (47.6 %) while a substantial portion of respondents indicate 11 to 20 years of farming experience (22.2 %). Lastly, the majority manages farms spanning from 8.1 to 18 ha in size (23.2 %) and 1.6 to 3.5 ha (20.7 %).

4.2. Descriptive statistics for study variables

Table 3 presents the means and standard deviations of the study

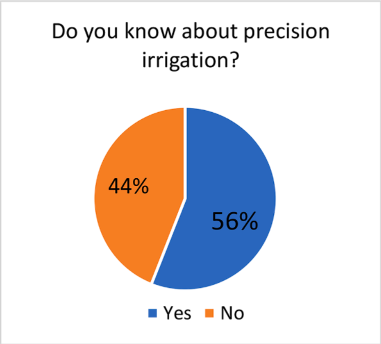

Fig. 2. Farmers' knowledge about precision technologies.

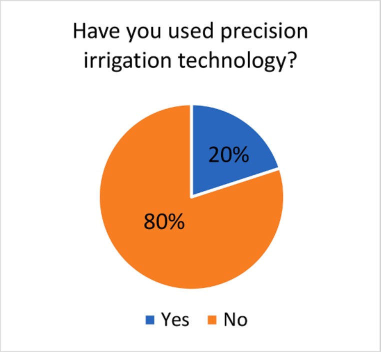

Fig. 3. Farmers' adoption of precision irrigation irrigation technologies.

Table 2
Sociodemographic and farm characteristics ($N = 82$).

Characteristics	Frequency	Percentage
Gender		
Female	8	9.8 %
Male	74	90.2 %
Age		
<25 years	15	18.3 %
25–35	18	22 %
36–45	20	24.4 %
46–55	18	22 %
Above 55	11	13.4 %
Education		
Elementary School	1	1.2 %
Middle School	3	3.7 %
High School	35	42.7 %
Undergraduate Degree	33	40.2 %
Postgraduate Degree	10	12.2 %
Total Annual Income		
<20,000 euros	42	51.2 %
20,000–40,000 euros	31	37.8 %
>40,000 euros	9	11 %
Farm Income %		
Up to 25 %	23	28 %
26–50 %	15	18.3 %
51–75 %	19	23.2 %
76–100 %	25	30.5 %
Farm Experience		
1–10 years	39	47.6 %
11–20 years	18	22.2 %
21–30 years	12	14.8 %
Above 30 years	12	14.8 %
Farm Size		
Up to 1.5 ha	12	14.6 %
1.6–3.5 ha	17	20.7 %
3.6–8 ha	14	17.1 %
8.1–18 ha	19	23.2 %
18.1–40 ha	12	14.6 %
Above 40 ha	8	9.8 %

Table 3
Mean scores and standard deviations of statements of study variables ($N = 82$).

Variables	Mean	S.D.
Perceived behavioural control	3.22	.73
Environmental consciousness	3.85	.65
Perceived economic benefits	3.74	.55
Perceived compatibility	3.81	.75
Risk aversion	3.47	.82
Intention to adopt	3.33	.84

variables, each with a sample size (N) of 82. Participants exhibited a balanced perception of control over the use of precision irrigation technologies, a notably higher level of environmental consciousness, a relatively high level of positive views on the economic advantages associated with precision irrigation, a relatively high degree of compatibility between precision irrigation technologies and existing farming practices, a fair level of risk aversion, and a moderate level of intention to adopt.

4.3. Factors affecting the adoption of precision irrigation in olive and cotton farming systems

Pearson correlations have been conducted to examine associations between variables which are presented in Table 4. Intention to adopt variable is significantly and positively correlated with perceived economic benefits, environmental consciousness, perceived behavioural control, and compatibility, but not with risk aversion. Furthermore, most constructs of the model were significantly intercorrelated except for risk aversion which has weak and non-significant relationships with the other variables. To assess the potential issue of multicollinearity, we calculated Variance Inflation Factor (VIF) values for the independent variables. The analysis revealed that VIF values for most variables were close to 1, indicating that multicollinearity is not a substantial concern within the regression analysis (Table 4).

Multiple linear regression analysis was subsequently conducted to examine the effect of the five independent variables on the intention to adopt. Regarding model-fit statistics, the Adjusted R-squared value of 0.503 indicates that the independent variables collectively explain approximately 50.3 % of the variation observed in the dependent variable. Moreover, the F-statistic is 17.427, accompanied by a significance level (*Sig. F*) of 0.000, indicating high overall model significance.

As can be seen in Table 5 among the five independent variables considered, four variables showed a significant relationship at a 5 % significance level while risk aversion was significant at the 10 % significance level. Remarkably, perceived behavioural control contributes positively with a coefficient of 0.263 ($p = 0.015 < 0.05$), indicating that higher levels of perceived behavioural control are associated with increased probability of adoption precision irrigation technologies (H1). Environmental consciousness exhibits a strong positive relationship with a coefficient of 0.361 ($p = 0.004 < 0.05$), where individuals with higher levels of environmental consciousness are more likely to adopt precision irrigation (H2). Similarly, perceived economic benefits demonstrates a positive association with a coefficient of 0.393 ($p = 0.007 < 0.05$), indicating that heightened perceptions of economic benefits lead to higher intention to adopt (H3). Perceived compatibility also plays a role with a coefficient of 0.235 ($p = 0.044 < 0.05$), signifying that perceived compatibility contributes positively to adoption (H4). Lastly, risk aversion exhibits a negative effect on adoption, as indicated by its coefficient of −0.149 ($p = 0.069 < 0.10$) (H5). Hence, all the hypotheses were supported. However, it's important to emphasize that this negative effect of risk aversion does not reach statistical significance at the conventional p-value threshold of 5 %. Instead, it falls just above this threshold, with a p-value of less than 7 %.

In Table 6, results in Messenia and Thessaly are presented. The means and standard deviations of each study variable for the two study groups, cotton farmers in Thessaly and olive farmers in Messenia, are presented, along with the results of the statistical test of significant differences between these two groups. On average, the intention to adopt was similar among cotton farmers in Thessaly and olive farmers in Messenia ($t(80) = -0.920$, $p = 0.360 > 0.05$). Similar results were found for perceived behavioural control ($t(80) = -1.394$, $p = 0.167 > 0.05$) and environmental consciousness ($t(80) = 0.750$, $p = 0.455 > 0.05$) where differences between olive and cotton farmers did not reach significance levels. However, a statistically significant stronger perception of the economic advantages associated with precision irrigation technologies was demonstrated by cotton farmers in Thessaly compared to olive farmers in Messenia ($t(80) = -2.575$, $p = 0.012 < 0.05$). In terms of perceived compatibility, no statistically significant differences were observed between the two groups ($t(80) = 0.680$, $p = 0.499 > 0.05$). Lastly, on average, cotton farmers in Thessaly exhibited a higher degree

Table 4
Pearson correlation of study variables ($N = 82$).

Variable	VIF	Intention to adopt	Perceived behavioural control	Environmental consciousness	Perceived economic benefits	Perceived compatibility	Risk aversion
Intention to adopt		–					
Perceived behavioural control	1.398	.523**	–				
Environmental consciousness	1.419	.525**	.337**	–			
Perceived economic benefits	1.399	.501**	.443**	.199*	–		
Perceived compatibility	1.703	.566**	.429**	.519**	.447**	–	
Risk aversion	1.008	−0.130	.037	−0.045	.057	.023	–

** Significant at $p < 0.01$.

Table 5
Results from the multiple linear regression analysis for the adoption of precision irrigation technologies in Messenia and Thessaly ($N = 82$).

Variables	B	Std. Error	Beta	t	p-value
(Constant)	−0.759	.609		−1.246	.217
Perceived behavioural control	.263	.106	.230	2.487	.015
Environmental consciousness	.361	.120	.281	3.010	.004
Perceived economic benefits	.393	.141	.257	2.776	.007
Perceived compatibility	.235	.115	.210	2.051	.044
Risk aversion	−0.149	.081	−0.145	−1.847	.069

Table 6
Comparison of Behavioural Factors between Olive Farmers in Messenia ($N = 40$) and Cotton Farmers in Thessaly ($N = 42$).

Study variables	Olive farmers in Messenia	Cotton farmers in Thessaly	Difference
Intention to adopt	3.24 (0.95)	3.41 (0.72)	–
Perceived behavioural control	3.11 (0.74)	3.33 (0.72)	–
Environmental awareness	3.91 (0.74)	3.80 (0.57)	–
Perceived economic benefits	3.58 (0.64)	3.89 (0.40)	*
Perceived compatibility	3.87 (0.76)	3.75 (0.74)	–
Risk Aversion	3.30 (0.86)	(0.75)	*

of risk aversion compared to olive farmers in Messenia. This difference was found to be statistically significant, but it's worth noting that it falls just below the threshold of 10 % ($t(80) = -1.888$, $p = 0.063 < 0.10$).

5. Discussion

The adoption of precision irrigation technologies in agricultural practices is a multifaceted process influenced by a variety of factors. In this section, we discuss the results of our study, which aimed to find the intricate web of behavioural factors affecting the adoption of precision irrigation technologies among farmers in the regions of Messenia and Thessaly in Greece. We selected five key factors—perceived behavioural control, environmental consciousness, perceived economic benefits, perceived compatibility, risk aversion—to explore their impact on precision irrigation technology adoption. Behavioural factors have been systematically neglected in previous studies on the adoption of precision irrigation. These factors were chosen based on their theoretical relevance and empirical evidence from previous studies in the field of technology adoption.

Findings from the questionnaire indicate that perceived behavioural control emerged as a robust predictor of farmers' propensity to embrace precision irrigation technologies. These findings align with the Theory of Planned Behaviour [69], which asserts that an individual's perception of control over a specific behaviour substantially shapes their intentions and, consequently, their actual conduct. This underscores the idea that farmers' actions are profoundly affected by their self-assuredness in their capacity to execute a particular behaviour, with this perception playing a vital role in predicting and comprehending adoption of precision irrigation in their farming activities. The presence of facilitating conditions or situational constraints change farmers' perceptions with respect to the ease or difficulty of performing a given behaviour [70]. In essence, our study revealed that farmers who exhibited a stronger sense of control over the adoption of precision irrigation technologies were significantly more inclined to adopt them. This outcome harmonizes with previous research in the realm of agriculture [71,72], which emphasized the importance of perceived behavioural control in sustainable farming practices adoption.

Regarding environmental consciousness our data revealed that individuals with higher levels of environmental consciousness were more inclined to embrace precision irrigation technologies. This inclination can be attributed to the profound sense of environmental responsibility that accompanies heightened awareness [65]. These farmers are probably more aware of the environmental challenges posed by traditional irrigation practices, climate change and recognize precision irrigation as a sustainable alternative. By significantly reducing water usage and minimizing the adverse environmental footprint of farming, precision irrigation aligns with their environmentally conscious values. This finding is in line with a growing body of literature [73,74] emphasizing the role of environmental considerations in influencing farmers' adoption of environmentally friendly practices and technologies. This emphasizes the need for strategies that induce long-term changes in individual behaviour towards environmental issues [51].

Perceived economic benefits have proven to be a significant predictor for the adoption of precision irrigation technologies. Our study indicates that farmers are more inclined to transition from conventional irrigation practices when they perceive tangible economic advantages linked to precision irrigation, such as increased productivity and cost savings. This aligns with broader insights from the literature [43,75,76]. Farmers need to be confident that the long-term benefits outweigh the costs, helping to mitigate uncertainties and apprehensions associated with the adoption of agricultural technologies [35,77]. This effect may be more pronounced in the Greek context where the majority of agricultural holdings are characterized by their small size increasing the perceived risks associated with new practices.

Perceived compatibility, in line with Technology Acceptance Model (TAM), stands out as a critical determinant in shaping farmers' intentions to adopt precision irrigation technologies. Those farmers who perceive precision irrigation technologies as harmonious with their existing agricultural practices, farming operations and values exhibit a higher propensity for adoption [56]. This reflects the fundamental principle that people's readiness to adopt an innovation depends on its alignment with their daily routines, goals, and values. Essentially, when farmers see precision irrigation technologies as a natural extension of their established routines, the perceived compatibility strongly influences their decision to adopt them [78]. These findings resonate with prior research [42,47,79,80] highlighting the critical role of perceived compatibility with current practices in shaping farmers' technology adoption decisions.

Furthermore, our study underscores the noteworthy, albeit marginally significant, impact of risk aversion on the adoption of precision irrigation technologies among farmers. This finding suggests that risk-averse farmers may be hesitant to adopt these technologies. This reluctance can be attributed to the inherent caution often exhibited by risk-averse individuals, who prioritize strategies geared toward minimizing financial risk in their agricultural operations. Precision irrigation systems necessitate an initial investment in specialized equipment and technology, which may be perceived as risky, especially when uncertainty covers technology performance and potential return on investment. Furthermore, risk-averse farmers may overestimate the probability of losses associated with new investments and may choose to maintain their current, familiar methods and technologies, avoiding risks associated with adopting new, unfamiliar technologies [81]. Hence, risk aversion can pose a significant barrier to adoption, even when precision irrigation holds the promise of long-term benefits. The finding that risk averse farmers are less likely to adopt precision irrigation technologies aligns with other studies [71,82].

In summary, our study underlines the important role of perceived behavioural control, environmental consciousness, perceived economic benefits, perceived compatibility, and risk aversion in the adoption of precision irrigation technologies. These findings highlight the significance of developing tailored educational and training programs aimed at farmers in these regions to build their capacities and increase their perceived behavioural control in integrating precision irrigation technologies into their olives and cotton farming activities. Furthermore, marketing campaigns and availability of information sources with respect to the impacts of climate change and the benefits of precision irrigation technologies could increase environmental awareness in the farming communities of these regions. CAP financial support schemes that support investment costs in new technologies as well as the development of both mandatory and voluntary schemes for the transition to more sustainable agricultural practices to tap the more risk averse/less environmentally conscious individuals versus more risk-seeking/more environmentally conscious ones are expected to foster adoption rates of precision irrigation technologies. The influence of risk aversion in adoption of new technologies underscores the pressing need for the development of innovative risk management tools specifically designed to mitigate uncertainty and alleviate concerns among risk-averse farmers. As precision irrigation continues to offer substantial advantages for both agriculture and the environment, our study emphasizes the importance of targeted interventions and support mechanisms to promote its adoption and foster more sustainable farming practices.

While our study contributes valuable insights into the behavioural factors influencing the adoption of precision irrigation technologies, it is essential to acknowledge certain limitations that may impact the generalizability of our findings. One notable limitation is the potential bias introduced by selecting farmers through collaboration with major farmer associations, as these affiliated farmers may hold different attitudes and practices compared to their non-affiliated counterparts. Moreover, the relatively small sample size further emphasizes the need for caution in generalizing our results. To enhance the robustness of future research in this area, we recommend incorporating larger sample sizes. Additionally, gaining insights from farmers representative of the general farmer population and extending the geographical scope of the study would contribute to a more comprehensive understanding of precision irrigation adoption in the Greek agricultural context.

6. Conclusions

In conclusion, this study explored the determinants of precision irrigation technology adoption among farmers in the Messenia and Thessaly regions of Greece focusing on olive and cotton growers respectively. Our study emphasizes the critical influence of environmental consciousness on farmers' intention to adopt precision irrigation technologies. Additionally, perceived economic benefits, perceived behavioural control, and perceived compatibility play significant roles in driving this intention. While risk aversion has a smaller impact, it remains a noteworthy factor in our analysis.

This study builds upon the Theory of Planned Behaviour and the Technology Acceptance Model to investigate the impact of various behavioural factors in the adoption of precision irrigation technologies in Greece. The research addresses the significant gaps in the literature which has focused mainly on farm and agro-ecological related factors, socio-demographics, and technology-related characteristics, thus, neglecting the importance of farmer individual characteristics and behavioural factors. Findings from this study have important implications for strategy implementation and policy design.

Future research may delve further into additional variables, providing a more comprehensive understanding of the intricate adoption process within precision agriculture in Greece and other European countries. Systemic factors, such as norms, information sources, extension and advisory services, legal framework, financial support are expected to significantly influence farmer adoption of precision irrigation technologies. Furthermore, additional methodologies could be employed to add more evidence on the farm decision making processes with respect to adoption of precision irrigation. Interviews could provide a more in-depth exploration of the process while experimental designs could establish causal relationships between behavioural factors and the intention to adopt.

Informed consent

Not applicable.

CRediT authorship contribution statement

Konstantina Kakkavou: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft. **Marilena Gemtou:** Conceptualization, Data curation, Formal analysis, Methodology, Writing – review & editing. **Spyros Fountas:** Conceptualization, Methodology, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare no conflict of interest.

Data availability

Data will be made available on request.

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